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SEDIMENTATION PROCESSES AND FACIES ON A SEMI-VEGETATED TALUS, LOUSTEAU, SOUTHWESTERN FRANCE

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ABSTRACT

A two-year survey of clast displacements on a small rockfall talus at Lousteau, southwestern France, shows that creep reaches up to 19 cm/month near the talus apex, whereas the distal segment remains stable. Movements are not distributed homogeneously but concentrate in distinct areas because of the deflection of clasts by vegetation patches. Sections across the talus reveal stratified deposits, thought to result from the lateral shifting of the tongues of very mobile debris. Poorly sorted gravel layers alternate with coarser debris corresponding to former pavements developed where sedimentation is reduced due to the protective effect of vegetation. Similar deposits have been found in larger, semi-vegetated taluses from the forest belt of the French Alps. Interactions between vegetation development and sedimentation, possibly controlled by the climatic changes during postglacial times, may be responsible for their stratification. Copyright © 1999 John Wiley & Sons, Ltd.

KEY-WORDS: rockfall talus; slope dynamics; stratified scree

INTRODUCTION

Stratified slope deposits are generally considered to form in bare, mainly periglacial environments (Dewolf, 1988; Van Steijn *et al.,* 1995). The processes invoked are accumulation by stone-banked solifluction sheets and lobes (Francou, 1988; Bertran *et al.*, 1995), debris flows (Van Steijn, 1988; Bertran and Texier, 1994), dry grain flows (Hétu *et al.,* 1995) or a combination of these mechanisms together with niveo-aeolian inputs, dirty snow avalanches, and the accumulation of clasts falling in isolation (Wasson, 1979; Hétu, 1991). However, a section in a modern, partially vegetated talus at Lousteau, southwestern France, has revealed a well developed stratification that cannot be explained by any of the above-mentioned processes. A two-year survey showed that no mass-movement occurred on the talus, and that stratogenesis was highly subordinated to the development of vegetation. This paper presents data on slope dynamics and facies observed in this talus, and a new sedimentary model that might explain the genesis of certain types of stratified screes is proposed.

PHYSICAL SETTING

Lousteau is located in southwestern France (0°25′25″E, 45°00′57″N), 120 km east from the Atlantic Ocean (Figure 1) at 65 m above sea level. The rockwall that gave birth to the small talus sheet investigated here was artificially created along a railway that has been abandoned since 1948.

The regional climate is characterized by a mean annual temperature of 11·5°C and mean precipitation of 850 mm, with a winter maximum. For the 1951–1980 period, the number of days with frost ranged from 33 to 79 (mean, 55). Snow is exceptional and does not last on the ground more than a few days.

The site microclimate is significantly colder than the regional climate because of the northern exposure of the rockwall. The frequency histograms of differences between the Périgueux meteorological

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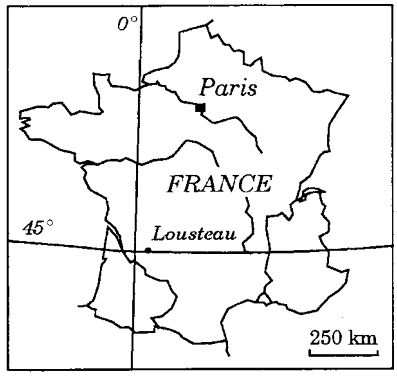

Figure 1: Location of the study site

station (used to define the regional climate) and the site where temperatures have been monitored for three years (Le Ber, 1988) show a mean value of 2°C for daily minima, whereas the maxima are similar. The temperature records of Le Ber (1988) for three consecutive winters showed that the wall surface underwent a significant number of freeze–thaw cycles, respectively 71, 56 and 73, i.e. nearly as high as the number of days with frost.

The parent rock is a Campanian chalky limestone with some marly intercalations. Porosity values (Le Ber, 1988) are characteristic of macroporous, frost-susceptible limestones (category III of Lautridou and Ozouf, 1978). The surrounding vegetation is an open oak forest. Since the abandonment of the railway, a bush vegetation has grown on the ballast and the talus foot. It consists mainly of hazel tree (*Corylus*), dogwood (*Cornus*), small oaks (*Quercus*) and blackberry bushes (*Rubus*).

METHODS

Longitudinal and transverse trenches have been dug in the talus to describe the lithofacies and to sample the deposits for clast morphometry, fabric, grain-size and micromorphology. Sedimentological data and slope angles were also collected from two additional longitudinal profiles.

The measurements of clast A-axis orientation and dip on sets of 30 to 50 clasts were treated according to Curray's (1956) method. This method makes it possible to calculate the orientation strength (vector magnitude, L) and to test the randomness of the distribution (Rayleigh test), p. We also used the eigenvalue method (Watson, 1956; Woodcock, 1977) that allows one to distinguish between cluster, girdle and random fabric patterns. The parameters have been computed using the software 'Stereo' (McEachran, 1990).

Some experiments were carried out in order to (1) measure the displacement of clasts, (2) evaluate the velocity of their burial, and (3) document the pattern of movement on a vertical profile. The experimental design consists of the following.

- Three lines of 50 painted stones parallel to the rockwall in the up-, mid- and downslope parts of the talus. A first set of markers was placed on 23 February 1995. The measurements made three and seven months after (26 May 1995 and 25 September 1995 respectively) were of limited interest because of the almost total disappearance of the paint. A second set of painted stones was subsequently placed on 25 September 1995. Displacements were surveyed twice, on 29 May 1996 and 4 October 1996.
- Two vertical columns of plastic rods, placed at respectively 1·5 and 3·4 m from the wall on 22 February 1995, and dug up on 4 October 1996, i.e. 19·5 months after the beginning of the experiment.
- Two steel shafts, driven into the scree up to 1 m deep, used as the reference line for measuring clast movements.

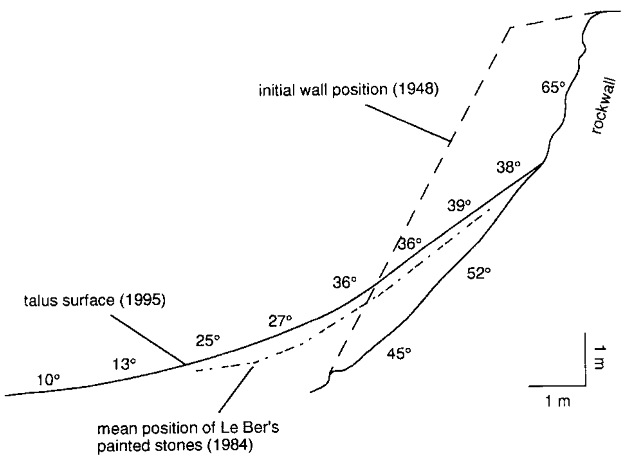

Figure 2. Talus profile

Figure 3. General view of the talus in 1984. A small meteorological station has been installed at the talus foot

Data on accumulation rates were also obtained from earlier experiments installed in 1984 by Le Ber (Le Ber, 1988), particularly stripes of paint extending from the wall to the footslope.

RESULTS

Talus morphology and sedimentology

The rockwall has a mean inclination of 65° and its present height reaches 2·7 m (Figure 2). Below the wall, the talus sheet presents an upper rectilinear segment with a mean inclination of 37·5° (about the two-thirds of the total length of the talus, i.e. 5 m) and a downslope concave segment (Figure 3). The ratio between H_o, the height of the talus, and H_i, the total height of the system wall + talus (Statham, 1976) reaches 0·57. This high value reflects an important retreat of the wall and the 'maturity' of the sedimentary system.

The talus surface displays a clear downslope coarsening trend of clasts (Figure 4). The mean size of the clast intermediate axis (B-axis) changes from 2·5 cm at the talus apex to 3·6 cm mid-talus and 7·0 cm

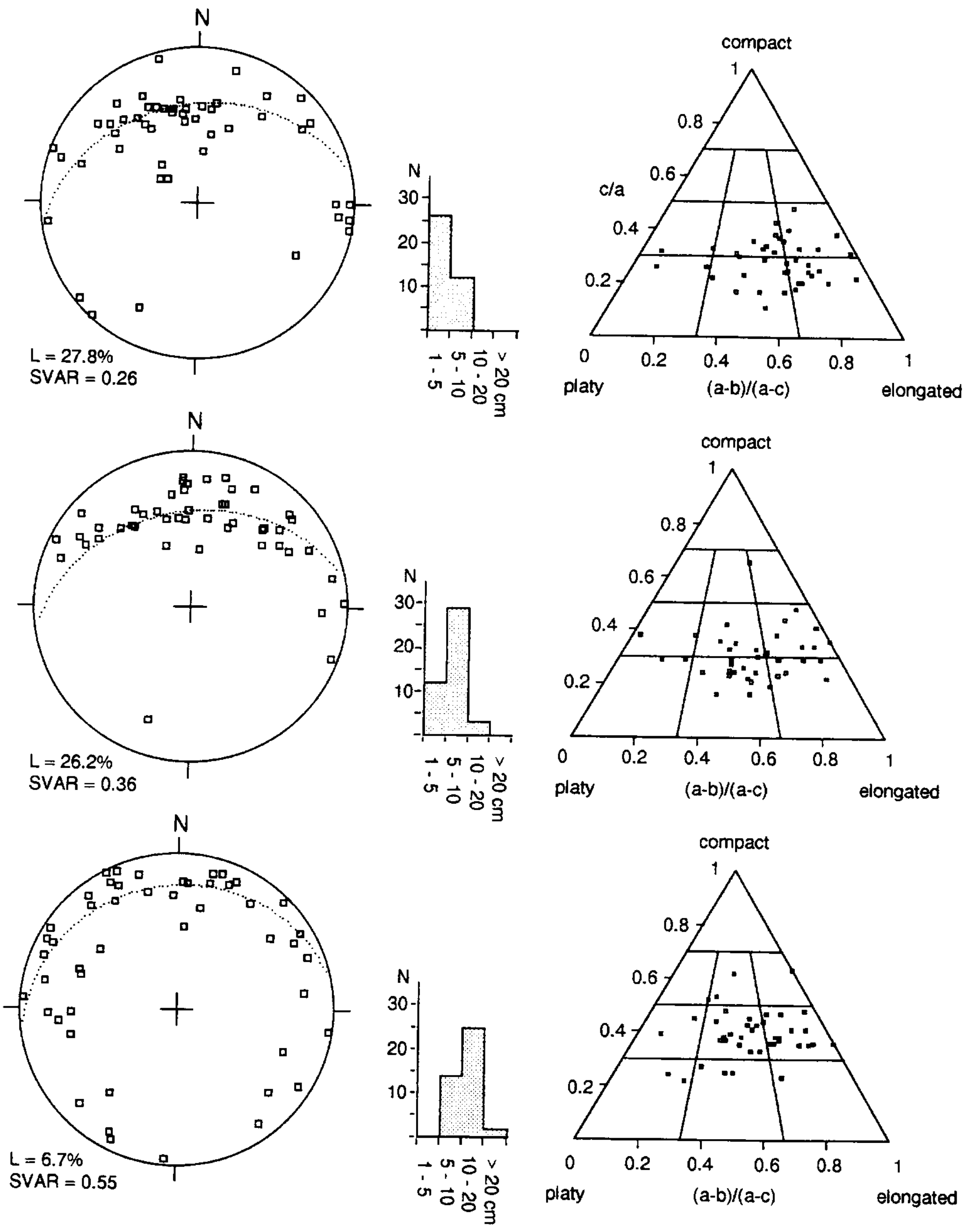

Figure 4. Fabric, grain-size and clast morphometry. Distance to the rockwall: A = 2 m, B = 4 m, C = 6 m

at the talus foot. This trend also concerns clast shape: mean flatness (C/A) changes from 0·28 to 0·31 and 0·39 respectively.

Clast orientation can be considered as random for the majority of the samples. L values are low (from 6·7% to 27·8 per cent) and p is generally over 0·05 (Table I). Only two samples coming respectively from the upper and the central parts of the talus, display a preferred orientation that is statistically significant ($p > 0{\cdot}05$). This preferred orientation is parallel to the slope. Fabric patterns are of girdle type ($0{\cdot}11 > K > 0{\cdot}52$), centred on the talus surface. A significant increase of spherical variance appears also from up- to downslope. This trend reflects an increasing dispersion of clast A-axes connected with the increase of clast heterometry and sphericity. Fabric patterns are similar to those commonly reported from other

Table I. Fabric characteristics. L (Vector Magnitude) and p (Rayleigh test) according to Curray (1956); E_1, E_2, E_3 (normalised eigenvalues), $r_1 = \ln E_1/E_2$, $r_2 = \ln E_2/E_3$, $K = r_1/r_2$ and SVAR (Spherical Variance) according to Woodcock (1977).

Sample location (distance to rockwall)	N	L (%)	p	E_1	E_2	E_3	r_1	r_2	K	SVAR
1·5	30	21·44	0·239	0·620	0·345	0·035	0·59	2·30	0·25	0·29
2	50	27·83	0·021	0·651	0·308	0·041	0·75	2·02	0·37	0·26
3·5	30	27·56	0·110	0·573	0·371	0·056	0·44	1·89	0·23	0·58
4	50	26·21	0·032	0·607	0·317	0·076	0·65	1·42	0·46	0·36
5	30	19·44	0·321	0·523	0·335	0·0142	0·45	0·86	0·52	0·61
6	50	6·71	0·798	0·509	0·419	0·073	0·19	1·75	0·11	0·55

rockfall screes (Caine, 1967; McSaveney, 1972; Francou, 1991; Bertran *et al.,* 1997). At the talus apex, the dominantly flat clasts come to a halt mainly after sliding and are subsequently affected by creep. They tend to exhibit a downslope preferred orientation. However the strength of the orientation remains low compared to that of mass-wasting deposits.

In the upper segment of the talus, the deposits appear in section as a massive, poorly compacted clast-supported diamicton. Coarse clasts (mean B-axis = 2·8 cm) are embedded in a loamy sand matrix (sand = 69·5 per cent, silt = 18 per cent, clay = 12·5 per cent). Grain size does not vary significantly from the base to the top of the deposit. Under the microscope, the material appears as a loose accumulation of heterometric clasts with scarce clayey silt coatings. This facies is overlain by a 2 to 5 cm thick openwork pavement. Downslope, the deposits display a stratification due to the interbedding of coarse matrix-poor lenses in a diamicton (Figures 5 and 6). The longitudinal and transversal extent of the lenses ranges from 1 to > 3 m, while their thickness varies from 3 to 40 cm, with a clear downslope thickening and coarsening trend. We do not observe any vertical sorting of the clasts, in contrast to the surficial pavement which shows a clear inverse grading. The grain size of the matrix is similar to that measured upslope (sand = 67 per cent, silt = 22 per cent and clay = 11 per cent).

Slope dynamics and the role of vegetation

The slope presents all the characteristics of a rockfall talus (morphology, slope, longitudinal grading, fabric pattern). During the bimonthly field surveys, we have never observed any surface feature that could be related to runoff activity, debris flows or dry grain flows, such as rills, levees or distinct debris lobes. However, the measurements of surface displacements show that the upper layer of the talus is affected by a very efficient surficial creep. The movements recorded from the first set of markers show the following features.

- Although only partially recovered, the downslope line has not undergone any displacement.
- At the first survey, about three months after the beginning of the experiment, painted markers from the two other lines were observed up to 75 cm downslope from their original position. Displacements were distributed along the whole experimental area. The second survey, seven months later, showed that maximum movements reached 110 cm for the upslope line and 80 cm for the mid-talus line. Again, no significant displacement was recorded for the lowest line.

For the second set of markers (Table II), the greatest movements were also recorded in the upslope line of painted stones and ranged from 53 to 400 cm, with a mean of 13·5 cm/month, approximately twice the mid-talus rate (7·34 cm/month). In spite of an important scatter, movements were not uniformly distributed along the line but clasts were about twice as mobile on the western part as on the eastern part of the scree. Displacement was also significantly greater during the winter period.

These results agree well with the data that have been previously published for rockfall taluses (Rapp, 1962; Church *et al.,* 1979; Gardner, 1979; Hétu, 1986; Francou, 1991; Pérez, 1993). For example, Rapp

Figure 5. Longitudinal section through a debris tongue. In the lower part of the photo, we can distinguish a coarse-grained matrix-poor layer buried by a non-sorted material. In contrast to the surficial pavement, this layer does not exhibit any clear vertical grading

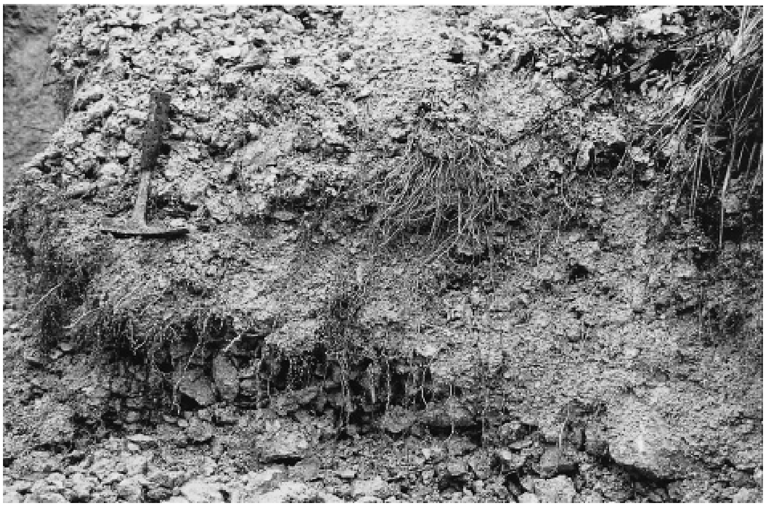

Figure 6. Transverse section of the stratified deposits

Table 2: Summary of marker movements at the talus surface.

	Number of markers	Number of markers lost	Mean displacement (cm/month)	Mean displacement between 25 Sep. 1995 and 29 May 1996 (cm/month)	Mean displacement between 29 May 1996 and 4 Oct. 1996 (cm/month)	Maximum total displacement (cm)	Minimum total displacement (cm)
Upslope line	50	15	13·5	19·1	2·4	400	53
Mid-talus line	50	18	7·34	8·25	6·0	252	11
Downslope line	50	0	0	0	0	0	0

(1962) indicates movements ranging from 0·5 to 10 m for two years on Swedish taluses, while Gardner (1979) gives mean annual values between 13 and 88 cm for an 11-year period in the Canadian Rocky Mountains. All authors have reported a downslope decrease in velocities of stones, with virtually no displacement at the talus foot. This is also consistent with Francou's (1991) sedimentary model. Accordingly, the upslope rectilinear segment of rockfall screes results both from accumulation and from downslope redistribution of the debris (talus shift), whereas the basal concavity forms in response to the primary accumulation of clasts and directly depends on the distribution of distance of particle travel during their fall. The transition between the two segments occurs within a small distance and corresponds to a break in slope called the ψ-point (Francou, 1991).

Talus shift at Lousteau is presumably provoked by (1) the impacts of stones falling on the talus, (2) trampling due to fauna (roe deer, rabbits), the tracks of which have been frequently observed during field survey, and secondarily (3) modifications due to raindrop impacts (splash creep), the surficial washing of fine particles (runoff creep) and wetting and drying of the deposits. The role of freezing and thawing is poorly documented. Although a significant number of (daily) cycles occurs at the surface, freezing does not penetrate at depth into the deposits as thermal minima rarely reach –5°C (Le Ber, 1988). These conditions do not favour ice lensing in the soil and so we speculate that frost-creep remains negligible. This is confirmed by the fact that particles follow individual trajectories, and that movement involves only the very surficial part of the deposits, as testified by the columns of plastic rods. However, pipkrakes may develop in the upslope fine-grained segment of the talus, particularly following rainy periods. Needle ice has actually been observed during the winter of 1996 and may account for the rapid clast movement during the winter.

Because of the small height of the rockwall, most clasts tend to stop in the proximal area of the talus. However, the critical stability angle seems never to be reached as indicated by the lack of mass movement such as dry grain flows. We assume this is a consequence of the high velocity of the downslope transport of debris by creep.

At the talus apex the strong mobility of the debris together with a high accumulation rate preclude the growth of a perennial vegetation cover. The uppermost 2 metres has a scarce and seasonal vegetation, mainly composed of *Pastinica sativa*, *Eupatorium cannabinum* and *Origanum vulgare*. At mid-talus clusters of herbs and small shrubs are able to develop. Excavation of some shrub specimens, particularly dogwood, invariably revealed buried portions of stems and branches that develop new roots (layering). The rhizomes of *Pastinica sativa* also typically exhibit a downslope elongated shape that is thought to result from the creep of the substrate. These patches of vegetation strongly influence the accumulation of debris: wedge-like tails of clasts form upslope of shrubs, and debris-protected low areas extend downslope (Figure 7). The latter have a dark colour due to the extensive development of a brownish patina and moss on blocks. The clasts falling on the talus and the surficial mantle of debris affected by creep are deflected towards open areas. As a consequence, instead of spreading all over the talus surface, debris concentrates in discrete tongues extending between the shrubs, allowing light-coloured, highly mobile material to progress over the more stable downslope pavement of coarse debris. These debris tongues do not possess any distinct front but become progressively thinner downslope and have a relatively diffuse boundary. Sections in the tongues show a layer with reverse grading composed

Figure 7. Surface pattern of the talus in 1995. Debris accumulation concentrates in light-coloured debris tongues that extend between the shrubs

of a surficial veneer of coarse clasts on a gravel partially filled with fine-grained (sieved) matrix. This material overlies a blocky layer with little interstitial matrix which represents a former pavement. Following burial, this pavement has been partially infilled by small gravels, giving birth progressively to a non-graded coarse deposit. At the talus foot, vegetation is denser and the groups of shrubs tend to coalesce. Sedimentation results from low-frequency accumulation of large stones that have penetrated through the vegetation.

Accumulation rates and wall retreat

The abandonment of the railway occurred in 1948 and corresponds to the maximum date for the beginning of sedimentation. Since the end of railway maintenance, the masonry wall has collapsed and rockwall retreat is nearly 1 m at the top and 1·3 m to the maximum, i.e. at the present talus apex. The bulk of fallen rock reaches *c*. 6.5 m^3/m. Remnants of the stripes painted by Le Ber at the talus surface in 1984 were also recovered in one of the trenches. The painted clasts are now buried under a debris layer that is 20–25 cm thick 2.5 m downslope from the wall, and 35–45 cm in the lower third of the talus. Taking mean values (we assume that the vertical dispersion of the painted clasts reflects both sieving and delayed burying because of creep) and a rock/rock + void ratio equal to 0·7, the total bulk of the debris accumulated since 1984 can be estimated to 1.35 m^3/m. This corresponds to a mean talus accretion of 2·5 cm/year. If we assume that the sedimentation rate was similar for antecedent periods, the date of the beginning of scree formation (i.e. probably that of the collapse of the supporting wall) should be 1959. However, the rate was probably higher during the initial stages of sedimentation since more than half the wall is now covered by deposits and does not contribute to debris production. However, taking 1959 as the date of the beginning of talus formation, the calculated wall retreat is extremely high and reaches 23·4 mm/year. This rate largely exceeds those measured for present or past periglacial environments, which usually range from 0·007 to 1·6 mm/year (maximal value: 3·29 mm/year) (Ballantyne and Harris, 1994). The high frost susceptibility of the parent rock, and the good water supply of the wall, probably explain this exceptional rate of wall retreat.

DISCUSSION AND CONCLUSION

The analysis of the talus at Lousteau clearly demonstrates that stratified deposits may originate from simple rockfall accumulation and do not necessarily derive from the piling of successive sheets or lobes

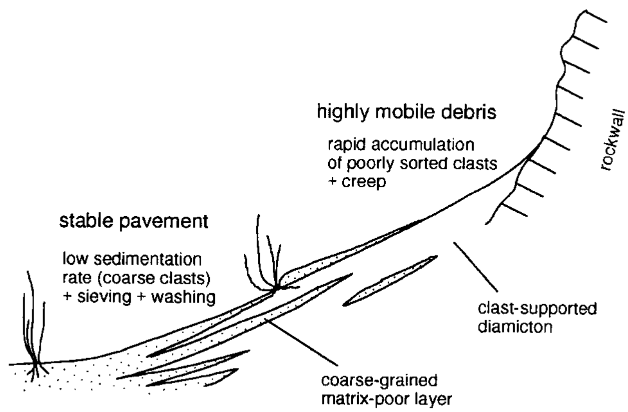

Figure 8. Schematic section of the talus

of debris emplaced by debris flows, grain flows, avalanches or solifluction as described by Van Steijn *et al.* (1995).

In the Lousteau example, stratogenesis is primarily controlled by the distribution of vegetation. The coarse openwork layers result from the burying of poorly mobile pavements corresponding either to clasts piled upslope from plant dams or to the accumulation of blocks at the talus foot. Burying of these pavements suggests that the debris tongues have migrated on the talus surface with time. We assume that three main mechanisms are involved: (1) a periodic disappearance of vegetation patches (burying of herbs, death of shrubs due to bouncing blocks or severe freezing periods); (2) a lateral displacement of the more productive areas of the rockwall; or (3) variations in debris production due to climatic factors (for example, pluriannual periods of severe frost-shattering). All three cases result in the progression of matrix-rich material over stable pavements, i.e. it can be regarded as the downward migration of the ψ-point as defined by Francou (1991). On the contrary, the role of creep strongly diminishes where sedimentation rates are lowered due to the protective effect of vegetation. In these areas, sieving and washing of the debris together with the accumulation of isolated stones give rise to aggradation and upslope extension of the pavement. The processes are summarized in Figures 8 and 9.

The mechanisms of stratogenesis probably started when a herbaceous vegetation had grown on the talus after an initial phase of homogeneous accumulation of debris following the collapse of the supporting masonry wall. Then these mechanisms have extended upslope because of the progressive colonization of the talus by shrubs. This does not conflict with the data provided by the examination of old (1984) photographs of the scree, which show a weaker development of shrubs, a smaller extent of the blocky pavement at the talus foot and a more regular downslope limit of the light-coloured sheet of fine-grained debris (Figure 3). We can hypothesize that such an evolution will include wider and wider areas as the vegetation cover increases and the rockwall retreats. At the same time, organic matter accumulation and other soil-forming processes will probably become dominant in the densely vegetated lower part of the talus.

Although the formation of the talus of Lousteau occurred within a very short lapse of time (a few decades), the high Ho/Hi value testifies to a rapid wall degradation resulting in an exceptionally high sedimentation rate. Lousteau can therefore be considered as a small-scale model for larger natural taluses with an evolution lasting centuries or millennia. A rapid examination of some taluses partially covered by vegetation in the forest belt of the French Alps and Pyrénées seems to agree with this hypothesis. As at Lousteau, no evidence for mass-movement has been observed at the talus surface, and it is assumed that creep and infrequent rockfall are the main processes involved in their present activity (cf. Gabert *et al.,* 1981). All the pits dug in the tongues or stripes of bare debris have revealed a sediment

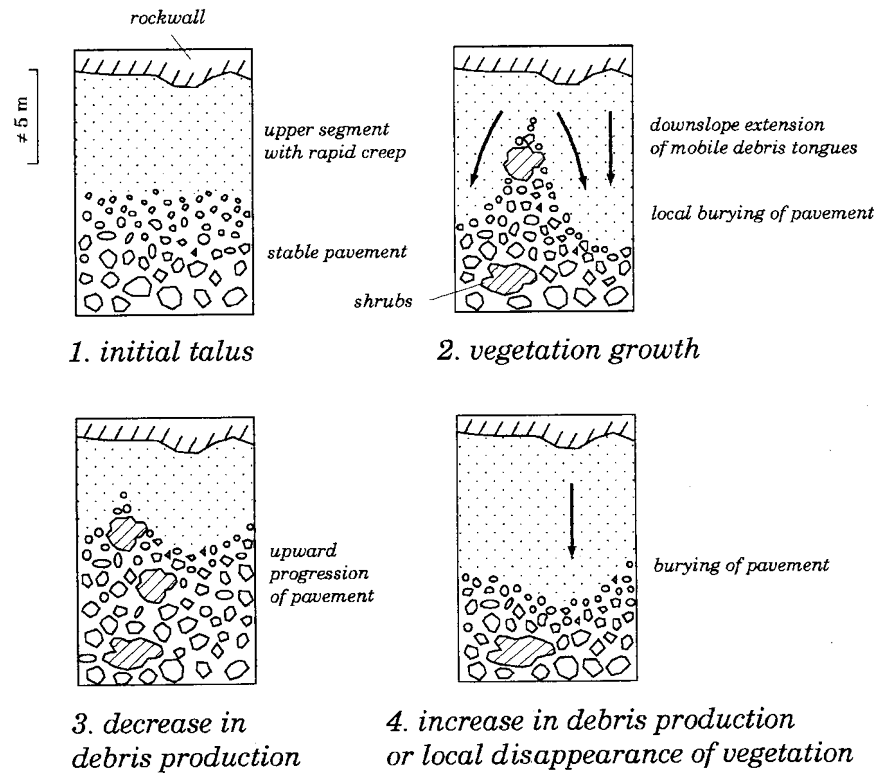

Figure 9. Mechanisms of stratogenesis (plan views of the talus)

organization similar to that described at Lousteau, i.e. a reversely graded layer of clasts, centimetres to decimetres thick, with an abundant matrix content at depth, overlying a matrix-poor, non-graded coarse material. The latter obviously represents a buried pavement. Larger sections in a small quarry open in a scree near Sisteron, southern Alps, make it possible to observe stratified deposits that are characterized by wide and thin (10–20 cm) beds of contrasted grain size. Gradings are poorly expressed. These deposits, the thickness of which is about 1 m, overlie a coarser-grained, massive material that corresponds to a more conventional rockfall accumulation.

We thus believe that the type of stratified deposit described here has a wide occurrence and probably represents a common stage of evolution for screes under present environmental conditions in France. Such a process may result from changes in local conditions as at Lousteau, and may be related to the 'normal' evolution of the rockwall–talus system (factors dependent on the velocity of wall degradation and vegetation growth), or may reflect climatic changes for larger taluses. The colonization of taluses by vegetation probably did not take place in a continuous and regular way during the Holocene. For example, the climate of the Little Ice Age was more favourable to debris production and talus aggradation as demonstrated by Grove (1972) and Ballantyne and Harris (1994). At the same time, the timberline was significantly lowered. This must have enhanced the extension of mobile debris at the expense of fixed areas, allowing stratified deposits to form. Grazing and trampling by sheep on steep slopes not suitable for cultivation were also more intense in the Alps during the last century and may have contributed to vegetation reduction and accelerated creep (cf. Schumm, 1967). Some other periods of climate deterioration have been recognized for the Holocene and their impact on slope dynamics is well documented (Brunsden and Ibsen, 1993; Jonasson, 1993; Matthews *et al.,* 1993). Therefore, similar deposits can be expected to have formed during a large part of the Holocene on many taluses.

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